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(54) **EDDY CURRENT FLAW DETECTOR**

(57) This invention prevents the failure of detection for horizontal and oblique lift-offs in a probe for an eddy current flaw detection test. Two detection coils (2, 2a, 2b) having mutually different diameters are concentrically disposed on the surface of a testpiece (1). These two detection coils (2) are differentially connected to a bridge circuit (3) for picking up a flaw signal. The two detection coils (2) are adjusted so that interlinkage magnetic fluxes generated inside the detection coils (2) by the eddy current become equal. An excitation coil (4) for inducing the eddy current in the testpiece (1) by AC driving is disposed over detection coils (2). The center of the excitation coil (4) is positioned on the center axes of the detection coils (2). An oscillator (5) for applying an AC current to this excitation coil (4) is connected to the coil.

Fig. 1(a)

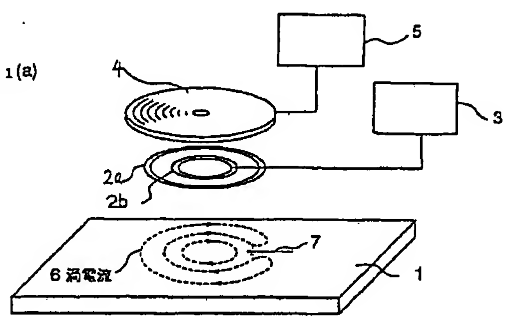
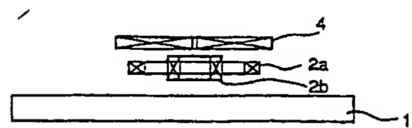


Fig. 1(b)



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Description

BACKGROUND OF THE INVENTION:

Field of the Invention:

The present invention relates to an eddy current flaw detecting probe used for an eddy current test for testing an internal flaw non-destructively.

Description of the Prior Art:

An eddy current test is now widely practiced for tests in manufacturing an iron and steel material and a non-ferrous metal material, maintenance inspection tests in various plants including small diameter tubes for heat exchangers and the like, and an eddy current flaw detecting probe is one of important factors which decide performance of a flaw detector.

One example of a prior art eddy current flaw detecting probe is shown in Fig. 11. Numeral 1 designates a test object, numeral 50 designates an exciting and detecting coil, numeral 51 designates an exciting coil and numeral 52 designates a detecting coil. In the prior art eddy current flaw detecting probe, there are used a bobbin coil, a pancake coil and the like as the exciting and detecting coil and the flaw detecting probe is divided into an absolute type [Fig. 11(a) and (b)] for testing yes or no of a flaw by impedance change in the respective coils 50, 52 and a differential type [Fig. 11(c), (d) and (e)] for testing yes or no of a flaw by differential component in the two coils 50, 52.

Also, the flaw detecting probe is divided into a self-induction type [Fig. 11(a), (c) and (e)] in which same one coil 50 carries out both excitation for inducing eddy current and detection of magnetic field by the eddy current and a mutual induction type [Fig. 11(b) and (d)] which comprises two kinds of coils of the exciting coil 51 for excitation and the detecting coil 52 for detection.

The differential type, especially, has an advantage, as compared with the absolute type, in dealing with noises caused by horizontal lift-offs in which a distance between the coil and the test object changes. In the prior art eddy current flaw detecting probe (especially of the absolute type), however, there occur lift-off signals due to lift-offs so that a flaw signal may be buried, which results in a problem to reduce a detecting power.

Further, even in the differential type which is generally good for lift-offs, in case of an inclined lift-off (Fig. 12) in which the probe inclines relative to the test object, there occurs a difference in distances l_1 and l_2 from the two coils 52 to the test object 1 to cause inclined lift-off signals, which results in a problem to reduce the flaw detecting power. It is to be noted that numeral 51 designates an exciting coil.

Also, in the eddy current flaw detecting probe shown in Fig. 11(e), there is less reduction in the detecting power against the inclined lift-off. This probe is constructed such that two coils, arranged to cross each other, are mutually in a differential connection. This probe has, however, a directivity in the detecting power and there is a shortcoming that it has especially less flaw detecting power in the angle of 45° to a scanning direction.

SUMMARY OF THE INVENTION:

It is therefore an object of the present invention to provide an eddy current flaw detecting probe of which detecting power does not lower against lift-offs and is improved in a directivity.

In order to attain said object, the present invention provides an eddy current flaw detecting probe constructed as follows:

(1) An eddy current flaw detector of Claim 1 of the present invention is an eddy current flaw detector constructed by use of an eddy current flaw detecting probe having coils for detecting displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe comprises two coils, having mutually different diameters, arranged coaxially and being in a differential connection with each other.

In this case, the construction is preferably a mutual induction type in which said two coils are detecting coils and there is provided an exciting coil coaxially with said two detecting coils.

(2) An eddy current flaw detector of Claim 2 of the present invention is an eddy current flaw detector constructed by use of an eddy current flaw detecting probe having coils for detecting displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe is constructed such that each one of said coils is arranged so as to have its center at each apex portion of a lozenge, a pair of said coils arranged on a diagonal of said lozenge are in a common mode connection with each other and two sets of said pair of coils in the common mode connection are in a differential connection with each other.

(3) An eddy current flaw detector of Claim 3 of the present invention is an eddy current flaw detector of self-induction type constructed by use of an eddy current flaw detecting probe having coils for measuring displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe is constructed such that each one of said coils having same characteristics is arranged so as to have its center at each apex portion of a lozenge, a pair of said coils arranged at the apex portion on a diagonal of said lozenge are in a reverse mode connection with each other and two

sets of said pair of coils in the reverse mode connection are in a differential connection with each other.

(4) An eddy current flaw detector of Claim 4 of the present invention is an eddy current flaw detector as set forth in (2) or (3) above, characterized in that said eddy current flaw detecting probe is formed and arranged in a plural number, adjacent two eddy current flaw detecting probes thereof commonly own one coil out of four coils, each one thereof having its center at each apex portion of said lozenge and there is provided a means for switching said eddy current flaw detecting probes.

In this case, there are arranged a plurality of the eddy current flaw detecting probes on a side face of a column-like base substance.

In each of the above-mentioned constructions, the coils for detecting magnetic field are adjusted so that interlinkage magnetic fluxes become equal unless there is a flaw in the test object.

According to the eddy current flaw detecting probes of the present invention constructed as above, following function and effect can be obtained:

In the eddy current flaw detector of (1) above, it is preferable to adjust a signal ratio electrically so that signals from the two detecting coils when there is no flaw are cancelled or to adjust a winding number ratio of the two coils so that interlinkage magnetic fluxes of the two coils when there is no flaw become equal.

If the above probes are constructed in the self-induction type, because there are differences in diameters and winding numbers of the two coils, there occurs a phase difference in the exciting signals generated at the respective coils to cause an irregularity in the distribution of the alternating magnetic field. But if they are constructed in the mutual induction type, the excitation does not relate to the state of coil and there occurs no irregularity in the distribution of the magnetic field.

Also, if the flaw detecting probe scans a portion where there is a flaw, the eddy current in the vicinity of the flaw in the test object changes and irregularity occurs in the alternating magnetic field generated by the eddy current. The irregularity in the magnetic field is detected first in the coil having a larger diameter. Thus, there occurs a difference in the interlinkage magnetic fluxes of the two coils and the flaw is detected.

In case there is a change in the horizontal lift-off, the distance between the flaw detecting probe and the test object changes, but because the two coils are arranged on a concentric circle, the interlinkage magnetic fluxes become equal so that a difference therein becomes zero and no lift-off signal is detected. Also, if there is a change in the inclined lift-off as shown in Fig. 13, the distance l from the centers of the two coils 2 (2a, 2b) to the test object 1 are equal as to the respective coils so that the difference in the interlinkage magnetic fluxes between the coils 2 is small and reduction of the lift-off signals can be attained. Further, because there is induced a circular eddy current on the test object 1 by the exciting coil 4, detection of flaw in every direction becomes possible.

According to the eddy current flaw detector of (2) above, eddy current is induced in the test object by excitation and a change in this eddy current is detected by the detecting coil which couples magnetically. The four detecting coils are constructed such that two coils on the diagonal are in the common mode connection with each other and two sets of these two coils in the common mode connection are in the differential connection with each other, which is seen as if two coils are in the differential connection.

The detection centers of the two sets of detecting coils in the differential connection are same because the four coils are arranged such that each one coil is arranged on each apex portion of a lozenge. Thus, changes in the horizontal lift-off are cancelled completely between the two coils in the common mode connection. Also, for the inclined lift-off as shown in Fig. 14, the detection centers of the two sets of coils 20, 21 in the common mode connection are same. Thus, even if the test object inclines, because the distance l between the detection centers and the test object does not change between each other, the lift-off signals can be reduced greatly.

It is to be noted that a common mode connection means a connection with a polarity of coil being in a same direction and a differential connection means a connection so as to take a difference in an output voltage: The common mode connection and the differential connection are shown in Fig. 15 in an equivalent circuitwise expression. These connections can be expressed also as shown in Fig. 15(b). In Fig. 15, a black spot shows a polarity of each coil and an arrow shows a direction of voltage generated by each coil. In Fig. 15, numerals 60a to 60d designate detecting coils and numerals 61a to 61d designate exciting coils. And the coils 60a and 60b are arranged at apex portions on a diagonal of a lozenge and the coils 60c and 60d are arranged likewise at apex portions on the other diagonal of the lozenge. The coils 60a and 60b are connected with a polarity of coil being in same direction, that is, in the common mode connection. Likewise, coils 60c and 60d are in the common mode connection. And a set of the coils 60a and 60b and a set of the coils 60c and 60d are connected so as to take a difference in the output voltage, that is, in the differential connection.

According to the eddy current flaw detector of (3) above, coils of same characteristics are arranged at apex portions of a lozenge, the coils arranged on a diagonal are in the reverse mode connection and two sets of the two coils in the reverse mode connection are in the differential connection. This example is shown concretely in Fig. 16. It is to be noted that the actual construction of this example is of the self-induction type but for purpose of easy understanding it is shown here in

netic fluxes in the detecting coils 2a, 2b of the inside and the outside. Thus, the difference in the interlinkage magnetic fluxes is detected by the bridge circuit 3 and the flaw 7 is detected.

Further, if there is a horizontal lift-off, because the two detecting coils are on a concentric circle and the interlinkage magnetic fluxes become equal, lift-off signals are cancelled and output of the bridge circuit becomes zero. In case of an inclined lift-off, because detection centers of the two detecting coils are at an equal distance each other from the test object, there is only a small difference in the interlinkage magnetic fluxes in the two detecting coils and lift-off signals are reduced.

Next, description will be made with reference to Fig. 2 on a case where the construction of the present embodiment is used for test of interior of a cylindrical test object such as a small diameter tube etc. Here, same part as that in Fig. 1 is given a same numeral and description thereof is omitted. In the test of a cylindrical test object such as a small diameter tube etc., the exciting coil 4 and the detecting coil 2 are fitted to a probe base substance 11, for example. But in case the cylindrical test object 10 has a curvature, the probe becomes inclined relative to central axis of the cylindrical test object 10. Nevertheless, by use of this probe, horizontal lift-off signals can be cancelled and inclined lift-off signals can be reduced. Thus, a flaw detecting power can be enhanced.

Next, a case where the present embodiment is used for test of an iron plate in a rolling process will be described with reference to Fig. 3. In case an eddy current test is to be done on an iron plate 15 in a rolling process, there is no constant lift-off of the iron plate 15 which moves at a high velocity on a moving device such as a roller etc. By use of the probe of the present invention, however, lift-off signals can be reduced, flaw detecting power can be enhanced and quality of the iron plate can be maintained.

(Second embodiment)

Fig. 4 is a schematic view showing concept of an eddy current flaw detecting probe of a second embodiment according to the present invention, wherein Fig. 4(a) is a perspective view of the eddy current flaw detecting probe, Fig. 4(b) is a plan view thereof and Fig. 4(c) is a cross sectional view of same. Also, Fig. 5 is a schematic view showing circuit construction of a detecting coil portion of the eddy current flaw detecting probe of the present embodiment. Over a test object 1 arranged are four detecting coils 20 (20a, 20b), 21 (21a, 21b) such that each one coil thereof has its center at each one apex portion of a lozenge. The four detecting coils 20a, 20b, 21a, 21b are so adjusted that there occur equal interlinkage magnetic fluxes when an eddy current 6 is in a regular state.

The two detecting coils 20a and 20b, and 21a and 21b, respectively, arranged on a diagonal, are in a common mode connection with each other and two sets of the detecting coils 20 and 21 in the common mode connection are in a differential connection with each other and are connected to a bridge circuit 3 for picking up a flaw signal. Also, over the detecting coils 20, 21, there is arranged an exciting coil 4 for inducing an eddy current 6 in a test object 1. The exciting coil 4 is connected to an oscillator 5 for supplying the exciting coil 4 with an alternating current.

In the present detector, unless there is a flaw, output of the bridge circuit 3 becomes zero. If there is a flaw, output of the bridge circuit 3 appears and the flaw can be detected.

Function of the present apparatus will be described. An alternating current is supplied to the exciting coil 4 from the oscillator 5 to induce an eddy current 6 in a surface of the test object 1. By this eddy current 6, an alternating magnetic field is generated and interlinkage magnetic fluxes caused by the eddy current 6 pass through the detecting coils 20, 21 so that an electric current occurs in the detecting coils 20, 21.

Unless there is a flaw, the eddy current is in a constant state to make equal the interlinkage magnetic fluxes in the detecting coils 20, 21 and output of the bridge circuit 3 becomes zero. If there is a flaw, the eddy current becomes irregular so that the interlinkage magnetic fluxes in the detecting coils 20, 21 become different between each of the coils and output of the bridge circuit 3 appears and the flaw can be detected.

Further, if there is a horizontal lift-off, because there is no difference, between the two sets of the detecting coils 20, 21, in the distance from detection centers of the two sets of the detecting coils 20, 21 in the common mode connection to the test object 1, lift-off signals are cancelled for a change of parallel lift-off. Likewise for an inclined lift-off, lift-off signals are reduced greatly.

Next, description will be made with reference to Fig. 6 on a case where the construction of the present embodiment is used for test of interior of a cylindrical test object such as a small diameter tube etc. Here, same part as that in Fig. 4 is given a same numeral and description thereof is omitted. In case the cylindrical test object 10 has a curvature, a probe 11 becomes inclined relative to central axis of the cylindrical test object 10. But by use of this probe 11, horizontal lift-off signals can be cancelled and inclined lift-off signals can be reduced. Thus, a flaw detecting power can be enhanced.

Next, a case where the present embodiment is used for test of an iron plate in a rolling process will be described with reference to Fig. 7. Here, same part as that shown in Fig. 4 is given a same numeral and description thereof is omitted. In case an eddy current test is to be done on an iron plate 15 in a rolling process, there is no constant lift-off of the iron plate 15 which moves at a high velocity on a moving device such as a roller etc. By use of the probe of the present embodiment, however, lift-off signals can be reduced, flaw

detecting power can be enhanced and quality of the iron plate can be maintained.

(Third embodiment)

Fig. 8 is a schematic view showing circuit construction of an eddy current flaw detecting probe of a third embodiment according to the present invention. It is to be noted that the eddy current flaw detecting probe of the present embodiment is driven in a self-induction type in which same one coil carries out both excitation and detection. Also, a black spot in the figure shows a polarity of the coil.

Two coils 30a and 30b, and 31a and 31b, respectively, arranged on a diagonal, are connected in a reverse polarity with each other. And the two sets of coils 30 (30a, 30b) and 31 (31a, 31b), respectively, in a reverse mode connection, are in a differential connection with each other. Each one coil of the detecting coils 30a, 30b is positioned at each one apex portion on a diagonal of a lozenge and each one coil of the detecting coils 31a, 31b is positioned at each one apex portion on the other diagonal of the lozenge.

With the above circuit construction, the coil 30a, for example, has a direction of the current reversed relative to the adjacent coils 31a, 31b. As the result, mutual induction which the coil 30a receives from the coils 31a, 31b is set off. That is, even if a variation occurs in the current in the coils 31a, 31b, the coil 30a is not affected thereby. Likewise as to the coils 30b, 31a, 31b, the respective coils are not affected by a variation in the adjacent coils.

(Fourth embodiment)

Fig. 9 is a schematic view showing construction of an eddy current flaw detecting probe of a fourth embodiment according to the present invention. A tube testing probe of the present embodiment is constructed such that the coils of the second embodiment, for example, are arranged on a circumference of a column-like probe base substance 40. One eddy current flaw detecting probe consists of four coils 41a, 41b, 42a, 42b. Also, one eddy current flaw detecting probe consists of four coils 41a, 41d, 42b, 42c. That is, the coil 42b is commonly owned by the adjacent two eddy current flaw detecting probes. Thus, probes (sensors) are formed on the entire circumference of the probe base substance 40. And by each of these sensors being switched electrically, the tube interior is tested along the circumferential direction and by the same being moved along the axial direction, the tube is tested along its entire length.

According to the present embodiment, a coil is commonly owned by the adjacent sensors, hence the number of coils in the circumferential direction can be lessened. Also, if four coils as shown in Fig. 10 are regarded as one sensor, a sensor 43a is overlapped portionally by sensors 43b, 43c in the circumferential direction, hence there can be reduced a dead angle in the detection sensitivity in the circumferential direction.

It is to be noted that the invention is not limited to the embodiments described above. For example, in the fourth embodiment wherein the plurality of sensors are formed and arranged on the side face of the column, the sensors may be formed and arranged on a base substance of other type than the column.

Also, the invention may be practiced with various modifications.

INDUSTRIAL APPLICABILITY:

The eddy current flaw detecting apparatus according to the present invention is constructed such that two sets of detecting coils are arranged to have a same detection center and these two sets of detecting coils are in a differential connection, thereby horizontal lift-off signals can be cancelled completely and inclined lift-off signals can be reduced.

Claims

1. An eddy current flaw detector constructed by use of an eddy current flaw detecting probe having coils for detecting displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe comprises two coils, having mutually different diameters, arranged coaxially and being in a differential connection with each other.

2. An eddy current flaw detector constructed by use of an eddy current flaw detecting probe having coils for detecting displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe is constructed such that each one of said coils is arranged so as to have its center at each apex portion of a lozenge, a pair of said coils arranged on a diagonal of said lozenge are in a common mode connection with each other and two sets of said pair of coils in the common mode connection are in a differential connection with each other.

3. An eddy current flaw detector of self-induction type constructed by use of an eddy current flaw detecting probe having coils for measuring displacement in a magnetic field due to eddy current induced in a test object by alternating current drive, characterized in that said eddy current flaw detecting probe is constructed such that each one of said coils having same characteristics is arranged so as to have its center at each apex portion of a lozenge, a pair of said coils arranged at the apex portion on a diagonal of said lozenge are in a reverse mode connec-

tion with each other and two sets of said pair of coils in the reverse mode connection are in a differential connection with each other.

4. An eddy current flaw detector as claimed in claim 2 or 3, characterized in that said eddy current flaw detecting probe is formed and arranged in a plural number, adjacent two eddy current flaw detecting probes thereof commonly own one coil out of four coils, each one thereof having its center at each apex portion of said lozenge and there is provided a means for switching said eddy current flaw detecting probes.

Fig. 1(a)

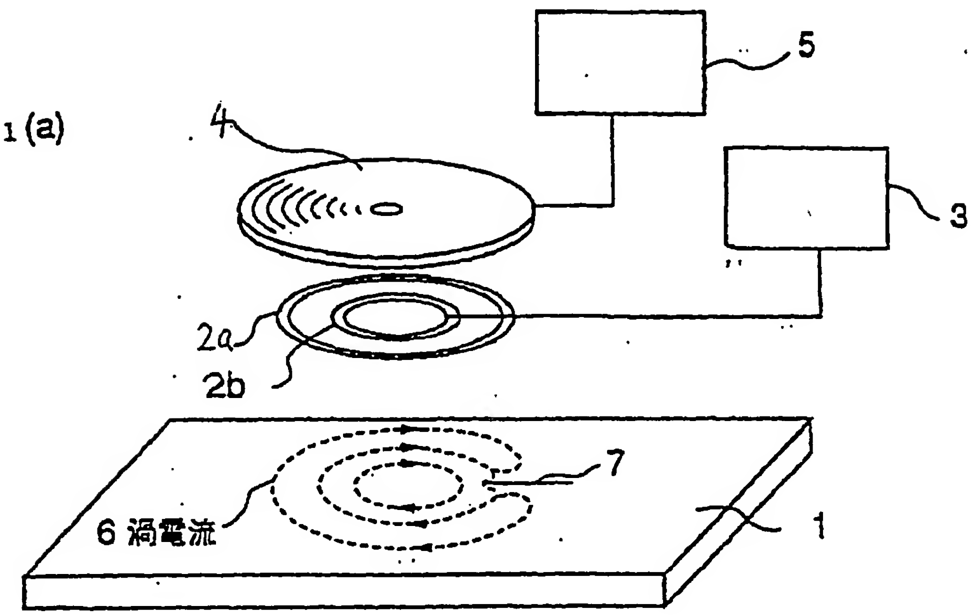


Fig. 1(b)

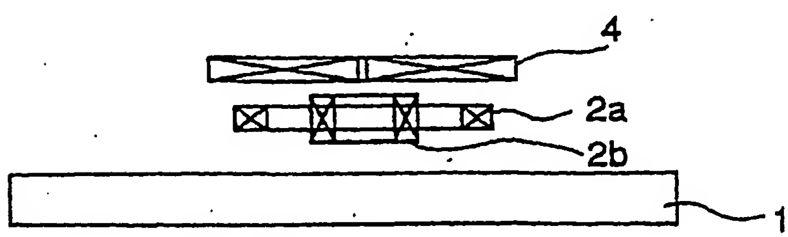


Fig. 2

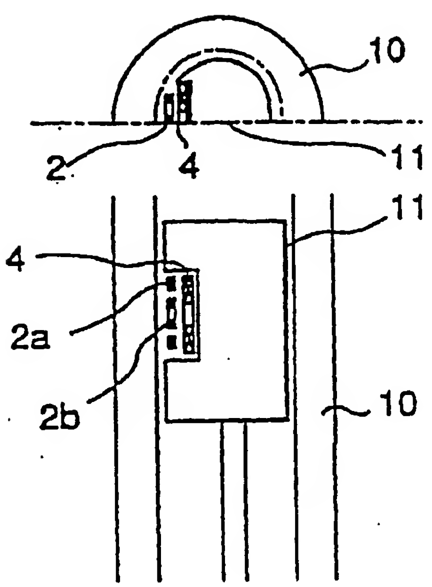


Fig. 3

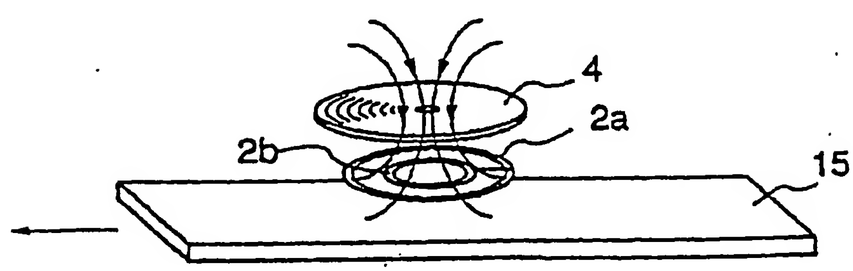


Fig. 4 (a)

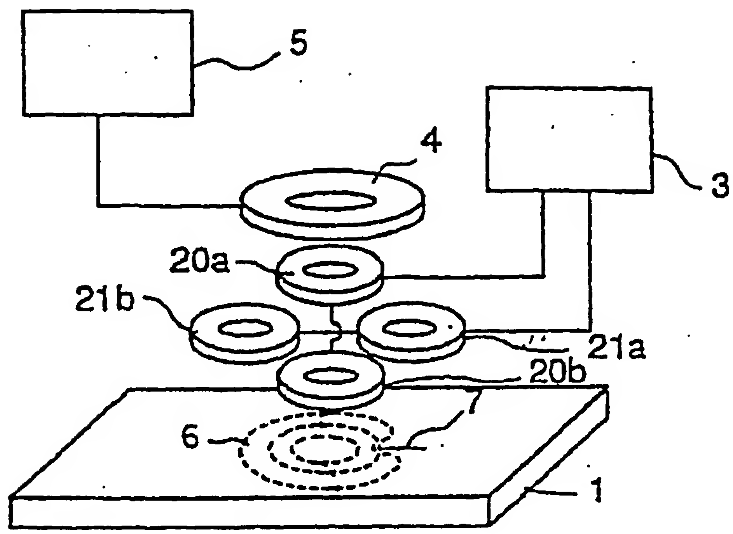


Fig. 4 (b)

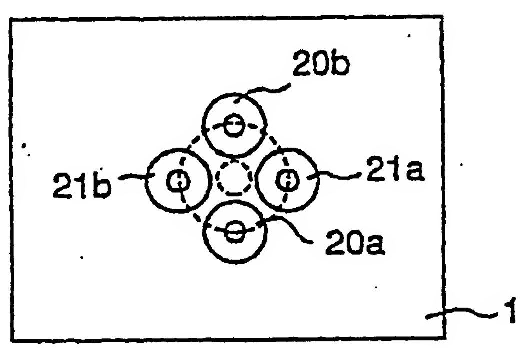


Fig. 4(c)

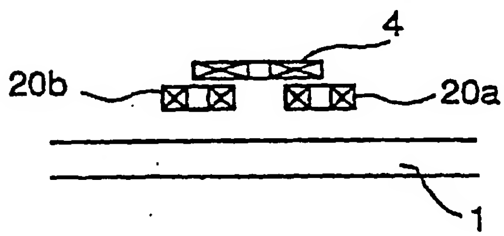


Fig. 5

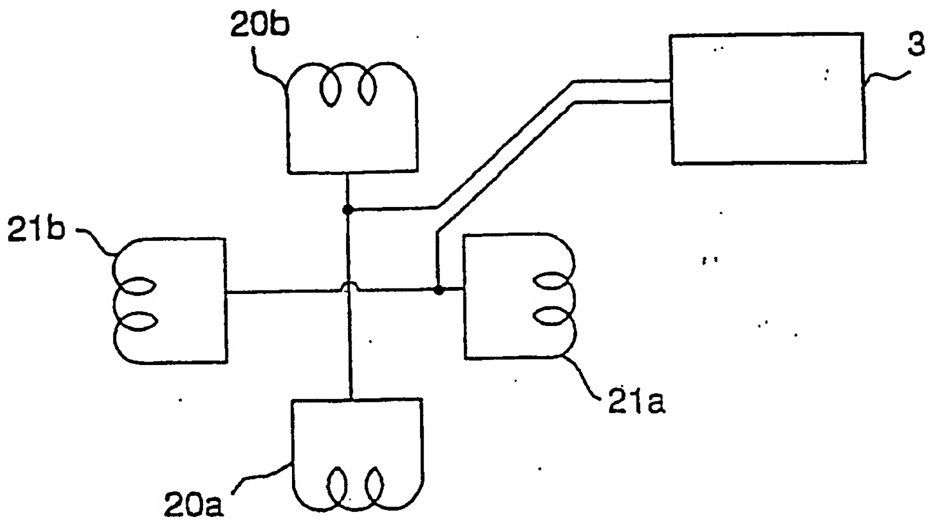


Fig. 6

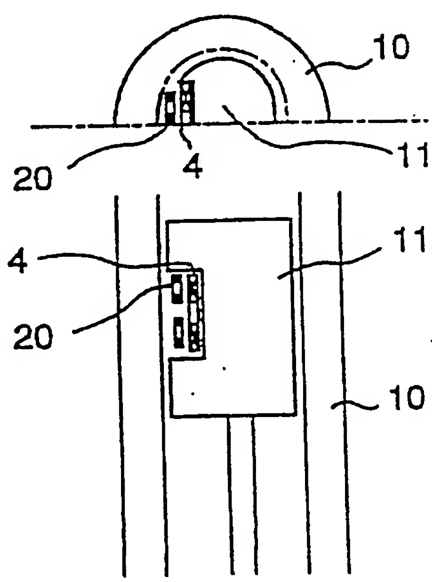


Fig. 7

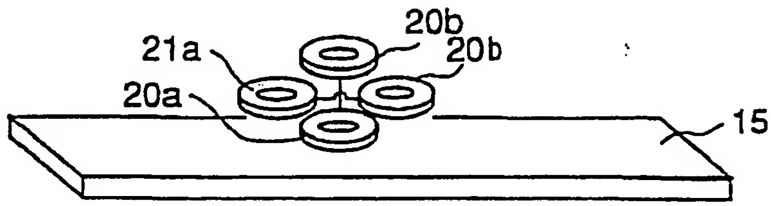


Fig. 8

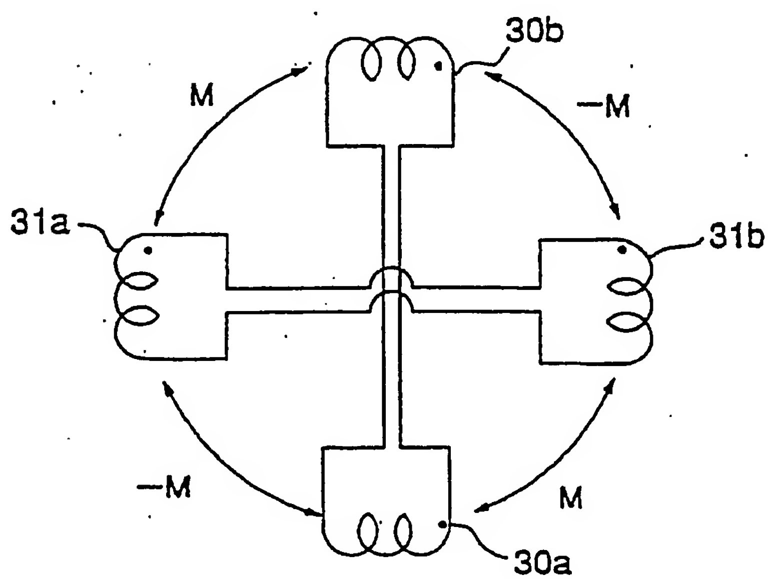


Fig. 9

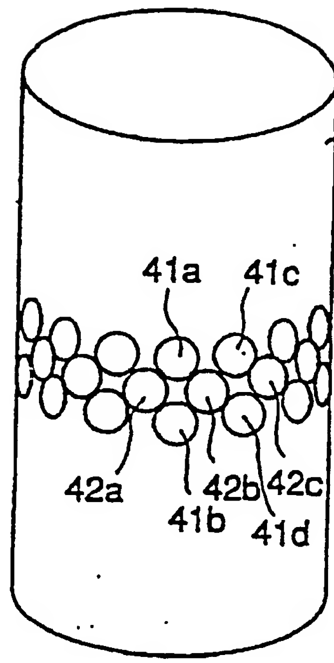
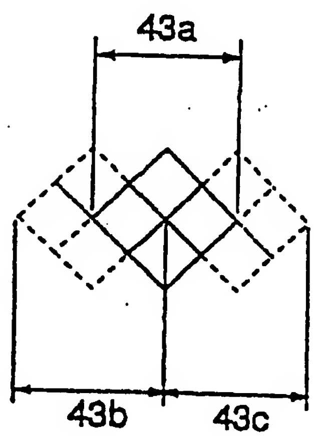


Fig. 10



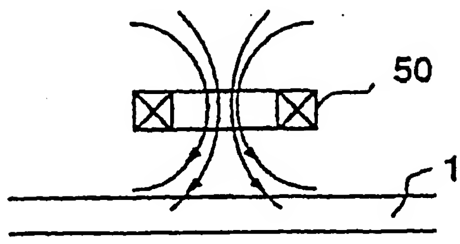


Fig. 11(a)

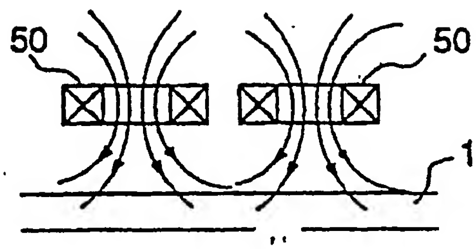


Fig. 11(c)

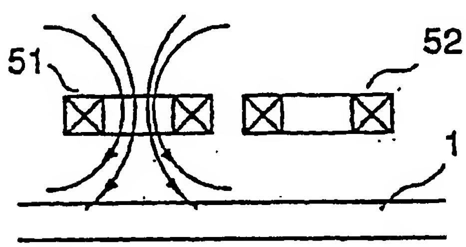


Fig. 11(b)

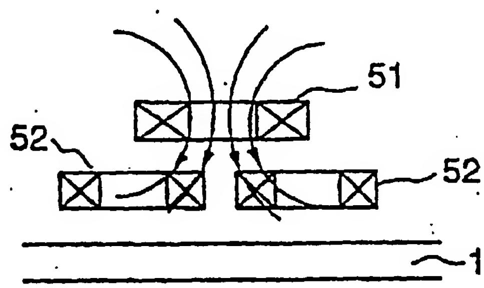


Fig. 11(d)

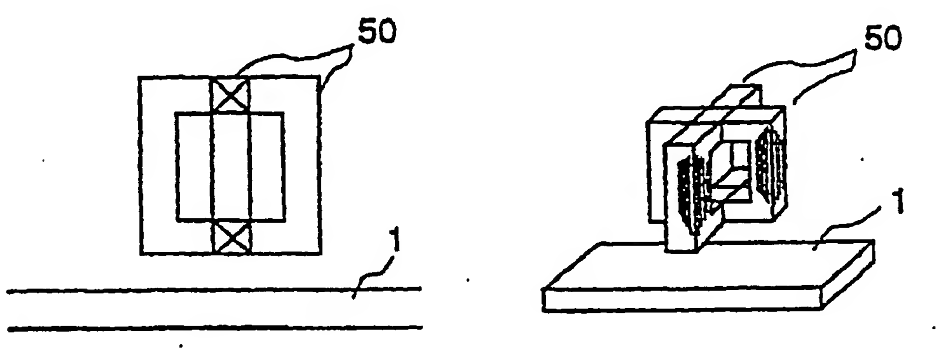


Fig. 11(e)

Fig. 12

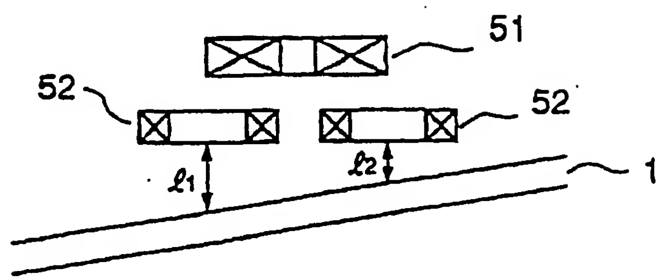


Fig. 13

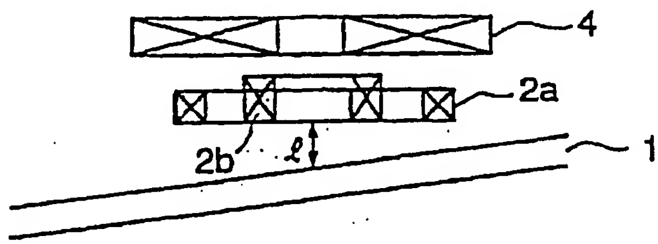
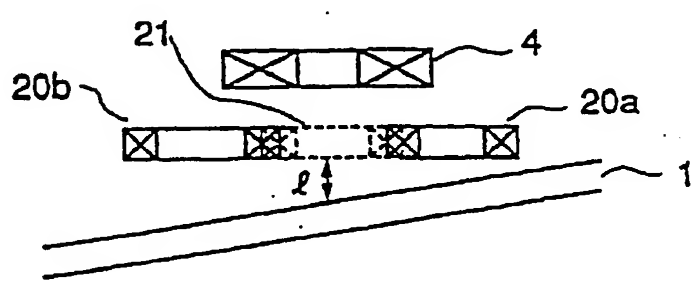


Fig. 14



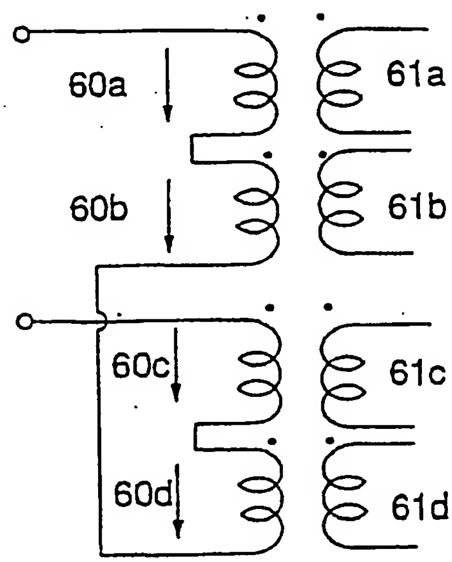


Fig. 15 (a)

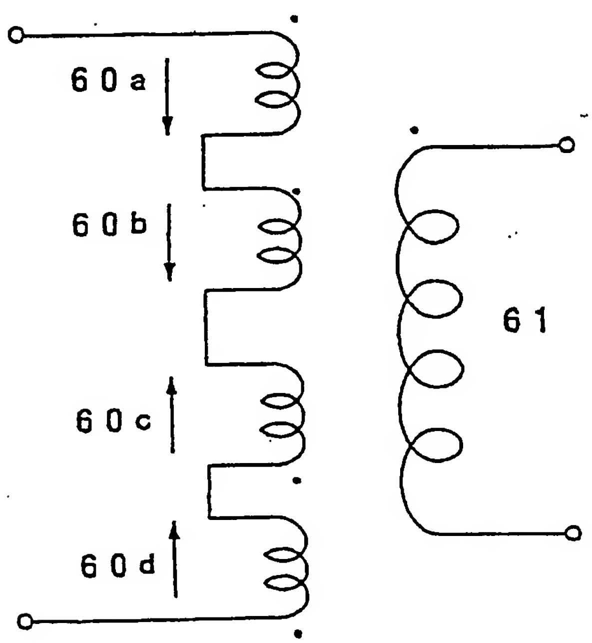
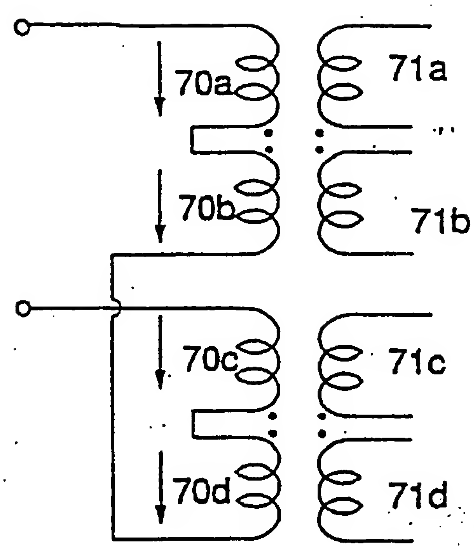


Fig. 15(b)

Fig. 16



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP97/00936

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^6 G01N27/90

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^6 G01N27/72-27/90

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Kokai Jitsuyo Shinan Koho 1971 - 1997

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP, 51-151590, A (Nippon Steel Corp.), December 27, 1976 (27. 12. 76), Page 2, upper right column, line 15 to lower left column, line 4 (Family: none)	1
Y	Microfilm of the specification and drawings annexed to the written application of Japanese Utility Model Application No. 37485/1972 (Laid-open No. 112392/1973)(Omron Tateisi Electronics Co.), March 30, 1972 (30. 03. 72), Page 3, line 10 to page 4, line 6 (Family: none)	2, 3, 4
A	JP, 5-133940, A (Tokyo Gas Co., Ltd.), May 28, 1993 (28. 05. 93), Paragraph (0031) (Family: none)	2, 3, 4

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
May 15, 1997 (15. 05. 97)	May 27, 1997 (27. 05. 97)

Name and mailing address of the ISA/	Authorized officer
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